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KEY ARCHITECTURAL ISSUES AND TRADE-OFFS FOR THE NEW MILLENNIUM AD VANCED TECHNOLOGY VALIDATION MISSIONS

by

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Abstract

The first block of New Millennium missions includes three deep-space missions and two or three Earth-orbiting missions. All arc expected to be launched during the three- year period of 1998 to 2000. Each mission is designed to validate a suite of advanced technologies judged to be important enabling elements of NASA's future lower-cost yet ambitious space and Earth science program.

Formulating the overall plan for these validation missions — including the logical ordering of them ---involved the simultaneous investigation and evaluation of several architectural issues such as the nature of the candidate advanced technologies, the technology content for each mission, the definition of candidate mission types which could serve as a "test track" for the technologies, the duration and nature of the primary and extended mission phases for each mission, the launch dates for the missions, assessment of various factors related to mission reliability and resiliency, concepts for mission operations, techniques for validating the technologies during the missions, prospects for science during the missions, launch vehicle options, synergies between New Millennium missions, benefits to future NASA missions, and various funding profile and costing issues.

This paper summarizes how these factors influenced the definition and selection process for the baseline New Millennium missions, with emphasis on the deep-space missions. Selected factors for the Earth-orbiting missions, some different from those shaping the deep-space series, arc also highlighted.

Key Architectural Issues

NASA's New Millennium Program (NMP) represents a significant departure from the agency's past mission strategy in several respects, the most visible being that it is a highly visible series of technology-driven missions connected firmly with the vision for NASA's space and Earth science mission strategy for the 21 st century[1,2]. A significant majority of NASA's past, present and future robotic (non-crewed) missions have been and arc shaped by the fundamental science objectives they arc designed to address (thus the term 'science-driven'). The few dedicated technology demonstration missions in NASA's plans (e.g., *Lewis* and *Clark*) arc not as firmly anchored to NASA's future science mission strategy as arc those in the NMP. This strong strategic linkage combined with a relatively constrained budget for the program leads to several interesting and challenging mission and systems architecture issues.

This paper first summaries the key factors that shape the overall boundaries of the NMP, and highlights some of the important mission- and system-level trade-offs that were made by the NMP Architecture Development Team (ADT) during the definition phase for the first block of NMP missions. This work was largely conducted during calendar year 1995, led by the author and ably supported by those mentioned in the acknowledgments at the end of this paper. Brief technical summaries of the NMP missions baselined to date arc also supplied at the end to provide the reader with a first-order sense of what resulted from this process.

In the discussion below, all NMP missions arc segregated into one of two categories: deep-space or Earth-orbiting. Both categories represent a sub-series of NMP missions which arc consistent with a set of mission- and systems-level constraints unique to that sub-series, jointly defined and agreed to by NASA Headquarters (HQ) and the Jet Propulsion Laboratory (JPL), which has been given responsibility to manage the program for the agency.

JPL will be responsible for implementing all NMP deep-space missions, in conjunction with a significant industry partner selected for each mission. For the Earth-orbiting series, JPL and NASA's Goddard Space Flight Center (GSFC) will share the implementation responsibilities, also with significant industry involvement.

As of mid-September 1995, the first block of three NMP deep-space missions has been selected and baselined, whereas only the first Earth-orbiting mission has been baselined(tentatively), as of mid-December 1995.

Definition work on the deep-space series benefitted from more than three years of concept study work at JPL and NASA Headquarters before the ramp-up of the NMP effort in fal I 1994, so most examples below arc taken from the perspective of these missions. Definition of the first two or three candidate Earth-orbiting NMP missions started in earnest spring 1995; this work is still underway and completion is expected by early 1996. Where applicable, certain important differences in the factors shaping the Earth-orbiting mission series arc highlighted in (his paper.

Given this context, the following arc some of the important issues that the NMP ADT had to consider when formulating the mission plans for the program,

Nature of candidate ad vane.cd technologies

NMP is chartered by NASA Headquarters to "do the hard things". The showcase NMP technologies involve hardware elements from most traditional spacecraft subsystems, space-ba.scd and ground-based software, ncw operational methods and techniques and innovative mission, system and subsystem architectures. Most of the candidate advanced technologies represent significant advances beyond the state-of-the-art and thus little if any in-space experience and heritage exists for thcrn.

A more detailed treatment of the candidate NMP advanced technologies appears in other papers[3,4,5,6,7]. NMP advanced technology Integrated Product Development Teams (IPDTs) were formed during the first half on 1995 to develop technology roadmaps for the program and to recommend candidate technologies for the early NMP missions. The IPDTs arc typically responsible for providing any technologies selected for a given mission, though there arc exceptions. IPDTs were formed for live discipline judged most likely to foster the breakthrough technologies the program seeks:

- Autonomy
- Microelectronics Systems
- Communications Systems
- Modular and Multifunctional Systems
- Instruments and Microelectromechanical Systems (MEMS)

In late 1995, the last IPDT was split into two to deal with the large scope of this discipline area.

Technology content for each mission

The New Millennium Program Manager at JPL holds the ultimate decision-making authority on which advanced technologies arc to be designated for a speci fic NMP mission. This decision (or set of decisions) is based upon inputs from the NMP Science Working Group (SWG), the IPDTs, the ADT, NASA HQ, and other collaborating partners -- plus a fair amount of engineering and programmatic judgment.

Work by all of these groups proceeded in parallel — not in series as onc might prefer — during most of 1995. This highly fluid environment rnadc the job of the ADT more difficult. To support the early mission definition work for both the dmp-.spacc and Earth-orbiting series, the ADT assumed reasonable advanced technology placeholders for each mission, based upon an extensive emerging technology data base compiled by the NMP startup team in fall 1994. As additional detail was generated by the IPDTs on their technology roadmaps and the specific advanced technology candidates, the ADT responded by refining the NMP mission models.

Some advanced technology candidates (e.g., solar electric propulsion as the primary source of AV, autonomous heliocentric optical-only navigation) were deemed by NASA HQ and the Program Manager to be 'essential' for the first NMP mission, which carried the added challenge of setting the tone for the entire program. Early decisions such as this at the program level simplified the ADT's work by limiting the number of options.

Definition of candidate mission types

The mission profile for each NMP mission is designed to serve as a "test track" for its designated suite of advanced technologies (thus, they become' technology-driven'). At the highest level, the goal is to design a mission that proves out the advanced technologies and capabilities in an environment and mission mode that is similar to the type of 21 sl-century science mission(s) targeted by the suite of technologies. An operating heuristic for NMP is that each NMP mission should convince a future science mission manager or principal investigator that the advanced technologies arc ready for use on their mission without an inordinate amount of tailoring and requalifying. Validating thcm at the mission and system level is important.

For a terrestrial analogy, if a company wants to convince future customers that the new features of a heavy-duty pickup are desirable, they do not just run it around an oval test track for several weeks – they take it to a rugged off-road site and run it hard there, too, with the intent of shaking out the weak links in the system design. They also put it through a series of focused tests and demonstrations which replicate as closely as possible the various ways the truck might be used day-to-day by the targeted customers. This philosophy is similar to that employed in many aerospace disciplines as well as in the computer and consumer electronics fields. Each NMP mission could therefore be viewed as a 'beta tester' for the advanced technologies.

For many technologies, simply getting them into the integrated space environment (vacuum, zero-g, radiation, thermal, dust/particle, operational) for durations of several weeks to a few years represents an adequate validation of their key attributes. But, particularly for the NMP deep-space missions, NASA HQ imposed the additional constraint that they must "go somewhere and do something interesting", effectively ruling out an otherwise adequate mission profile that simply placed a high-tech vehicle on an Earth-escape trajectory to nowhere.

At the other extreme, some high-priority technologies require a fairly specific mission profile or sequence in order to put them through their paces, similar to what is required for mission-specific fly-off validations of advanced aircraft and missiles. For example, validation of an autonomous target flyby imaging capability demands at least one target -- such as a near-Earth asteroid or a comet — and a flyby trajectory. The trajectory must satisfy at least some basic geometric constraints (flyby distance, approach phase solar illumination, etc.), and if the imager itself is also an advanced technology, then specific requirements on the nature of the target (size, albedo, spectral characteristics) may also be imposed. In some cases, several advanced technologies must be demonstrated together at the system level to satisfy the validation objectives, in which case additional mission profile and/or sequencing constraints might be warranted.

Mission reliability and resiliency

Many of the technologies on a given NMP mission are designated to be the only source of an important function on the spacecraft, such as on-board computing, telecommunications or main propulsion. The result is that each NMP mission takes on a fair degree of risk by implementing several brand-new technologies into a (typically) single-string design. The mission and systems architecture for each candidate NMP mission must accommodate the interfaces and nuances of each advanced technology while carefully balancing their inherent risks. With several advanced technologies on each mission, this is a challenge.

Without going into detail here, some of the heuristics and techniques used to mitigate mission and programmatic risk and to provide some flexibility include:

- Avoiding over-optimization of anything
- Getting early program commitments and decisions, including multiple readiness gates for the advanced technologies
- Categorizing some technologies as "experiments" and making them stand-alone elements of the system design
- investigating and articulating technology and mission descope options
- Designing in graceful degradation and functional redundancy
- Designing healthy margins into subsystem designs and mission profiles
- Identifying multiple launch windows and multiple candidate targets
- Careful planning and execution of the ground-based demonstration and test program
- Bookkeeping adequate development cost and schedule reserves

Launch dates

Among several other high-level objectives, NMP is chartered to continue pushing NASA into the 'faster, better, cheaper' mode. of business. Early program guidelines from NASA HQ called for a first NMP launch (a deep-space mission) no later than 2-3 years from the start of the program, with subsequent deep-space launches approximately each year thereafter. The earliest achievable launch dates were set primarily by the expected NMP funding profile for the first few years, the earliest readiness dates of the candidate advanced technologies, and the expected readiness dates of the candidate launch vehicles, many of which were new configurations. With these factors in mind, a first NMP launch in late 1997 or early 1998 was baseline.d. The start of the proposed Earth-orbiting series — also on approximate one-year centers -- was deferred to late 1998 due to the later start-up for this component of the program and because of funding profile restrictions.

At least one deep-space mission is actually a piggybacked payload on another scheduled NASA science mission: the NMP Microprobes on the. Mars Surveyor Program's 1998 lander mission. For this NMP mission (see more below), the launch date is, of course, set by the host mission.

in a similar vein, 10 satisfy selected validation objectives, as described later, some of the NMP Earth-orbiting missions may bc designed to rendezvous alongside another Emlh-observing spacecraft. In such scenarios, the launch dates for the NMP missions must bc correlated with the planned operational missions for the other spacecraft.

Duration and nature of primary and extended mission phases

The primary mission phase of each NMP mission comprises the required mission activities for that mission. Where appropriate, car] y technology validation is desired during each mission to ensure rapid feedback to the technical community and prompt technology infusion into subsequent NMP missions and into other planned NASA science missions. Shorter mission durations arc also desired to help minimize the life-cycle cost of the NMP. Desired primary mission durations for ciccp-space missions arc typically 1-3 years, whereas the Earth-orbiting durations are typically 6 months to a year.

Each NM1' mission is also incentivized to attempt bold validation objectives during extended mission operations, in the way that *Magellan* demonstrated aerobraking at Venus after completion of its primary mapping mission. (Recall that the entire spacecraft was sacrificed at the end to acquire onc last important set of atmospheric validation data.) This phase will bc used to conduct particularly risky technology validation operations (such as purposely injecting faults into the system to evaluate selected fault protection routines) and to push the envelope a bit farther for many of the technologies. Novel operations modes may aiso bc attempted during this phase, such as turning mission operations over to students.

Concept of mission operations

NASA has already initiated an agency-wide effort to reduce the costs associated with operating its deep-space and Earth-orbiting missions. Lower-cost operations will bc essential in the future as increasing numbers of capable missions in the 'faster, better, cheaper' mode arc launched and more are in their operational phases simultaneously.

At a high level, the vision for mission operations in the time frame of 2010 and beyond includes more frequent launches (perhaps onc or more science missions pcr month), icss frequent tracking of individual spacecraft, iligi]cr-level commanding and telemetry, and a proliferation of ncw mission architectures involving small spacecraft, constellations and networks. More emphasis will bc placed on using operational standards and protocols, statistical management of the spacecraft fleet, and a move away from cuslom-designed, expensive enc.-of-a-kind systems.

NMP will contribute to this transition by demonstrating and validating --- probably in wc]] defined steps - several ncw capabilities needed to enable this vision: a spectrum of onboard and ground-based autonomy (including fully autonomous vehicles), onboard data editing and assessment, goal-directed commanding, event-driven sequencing, and "beacon mode" telemetry, to name a few. The latter capabilit y refers to the notion of sending only a specific tone to the Earth (rather than telemetry data) which summarizes tile overall status of the spacecraft, One tone might mean, "I'm fine, leave mc alone", whereas another would mean, "i had a subsystem problem yesterday and have been unable to resolve it, so please schedule a couple of telemetry passes in the next week and I'll send an engineering summary to you".

Ail NMP missions will bc designed to contribute to the realization of this vision. For some, day-to-day operations will be conducted under a ncw paradigm, whereas others might include tile demonstration of a new operations technique or process as an experiment during a small fraction of its mission. The challenge is to incorporate these plains into tile larger campaign of validating multiple advanced technologies, each of which has specific operational requirements.

Validation techniques

All NMP advanced technologies must bc a) breakthrough in scope, b) a high priority for the science missions of the 21st century, and c) in need of space-based validation[1,2]. Arriving at a crisp definition of the last criteria has been an elusive endeavor for the NMP team. Wc now realize that each technology is unique and thus no onc definition works for all. As mentioned above, some technologies jusl need to bc operated in the integrated space environment for a certain duration. Others need to bc functionally demonstrated at the mission and system level, perhaps along with several others or singly as part of a specific operational sequence. Each technology is different, and each mission is different. Validation of some capabilities (vs. technologies) may require phased validation over several NMP missions.

Philosophically, NMP intends 10 approach the challenge of using these largely untried advanced technologies head-on: in most cases, no 'conventional backup' technology will bc included as a crutch in case the breakthrough technology fails or degrades. Thus, tile team's efforts (and available resources) will be focused on learning as much as possible about the ncw technologies and figuring out how to make thcm work in a real systcm in a realistic operational environment.

in fact, NASA HQ's guidelines for NM}' state that the attainment of the technology validation objectives take precedence over mission risk reduction, in effect providing a license for this gutsy approach. For the first NMP deep-space mission, 90% of the mission objectives arc focused on acquiring validation data; the remaining 1 O% relate to acquiring science data (see below).

Particular attention will be paid to understanding the functional redundancies in each system, since most will be single-string designs. For specific high-risk design features, selected block redundancy may be used to assure validation requirements arc met.

For the first deep-space mission, the mission objectives include a possible 10% 'extra credit' beyond the baseline 100 should the ambitious extended mission prove Successful .

Technologists affiliated with each technology will demand that a minimum engineering data set be returned to the ground for analysis. Some technologies will impose requirements on the system to provide independent validation or calibration data to confirm proper performance. For example, validation of the autonomous onboard optical-only heliocentric navigation capability planned for the first deep-space mission may wc]] rely on occasional radio-based navigation passes for an independent check. Little if any of the validation data needs to be returned and analyzed immediately; this lends some flexibility to the mission engineers and allows them to push back on typical science mission requirements for higher telemetry data rates and frequent tracking passes.

The NMP Earth-orbiting missions have to satisfy a special validation requirement that strongly shapes the mission and system designs: ensuring instrument data continuity. What this means is that each NMP Earth-orbiting advanced instrument technology (which is the focus of the NMP Earth-orbiting series) must be compared to whatever its analog is the existing suite, of Earth-observing instruments and measurements. The science data performance of the new instrument must be as good or better than the old, otherwise it is deemed useless. The rationale for this constraint is that most of the Earth observation models — now quite mature and sophisticated — utilize years if not decades of precisely calibrated science data as inputs. Any introduction of advanced technology must assure that the quality of these data streams is maintained. It is this requirement which leads to the concept of co-orbiting the NMP spacecraft with another F.arth-observing spacecraft, taking the same type of data at the same time for subsequent direct comparison.

In all cases for the NMP advanced technologies, thorough ground-based testing and validation will be conducted -- also at the system level - to verify the system design and to enhance confidence that the technologies will work in the space environment.

Prospects for science

The New Millennium Program is fundamentally driven by the vision for NASA space and Earth science missions in the 21st century. This view of the future helps to prioritize which capabilities and associated advanced technologies need to be validated. This dots not rncan, as stated above, that each NMP mission is science-driven.

Nevertheless, the NMP charge to "go somewhere and do something interesting" combined with the goal of convincing future science mission principals that the advanced technologies do indeed work provides the opportunely to conduct some relevant and meaningful science during each NMP mission, In fact, returning real science data is a sure way to prove that an advanced prototypical science instrument works (or doesn't!) as intended, for instance. A similar argument can be made to support the validation of an advanced operational technique or novel system architecture: if good science can bc acquired while using it, it's probably a good concept.

l'bus, each NMP mission will include a science component. The twist here is that the science supports the validation objectives; it is not allowed to drive the mission and system designs to the degree that science drives most other NASA missions. This is especially true for the NMP deep-space missions. A case in point: for the first deep-space mission, the NMP Science Working Group supported the ADT extensively in the trades about whether to send the spacecraft on a flyby to an asteroid and comet (the selected baseline mission profile) vs. an asteroid rendezvous or comet rendezvous (both rejected options). However, with the baseline dual-flyby profile selected, the SWG has played a minimal role in deciding which asteroids and comets to target; these decisions — still pending --- will largely be made by the mission engineers and technologists, with nominal support from a mission scientist and associated science advisory group.

It is expected that for the NMP Earth-orbiting missions a greater volume of usable science data will be returned from each mission due to the severe constraints on data continuity described in the previous subsection.

Launch vehicle options

NMP funding profile considerations drive all launch vehicle decisions toward the smaller end. Smaller is less expensive — as long as you don't go overboard trying to force-fit the spacecraft into the smal ler fairing. The NMP charter of enabling NASA's vision of fleets of small, capable spacecraft also drives the launch vehicle size the same direction: it would appear hypocritical to launch a single NMP spacecraft on onc of the largest available launchers, for example, even if affordable. This is an image thing. For this latter, more subjective consideration, guidance was supplied by NASA HQ: try to stay on the lower end of the medium-class vehicles, or smaller.

Onc significant, early NMP programmatic accomplishment was the agreement between NASA HQ and JPL/NMP to baseline life-cycle costing for the program. This means that the costs of the spacecraft (including advanced technologies), launch vehicle and operations for each mission — and indeed across missions --- can be freely traded with the intent of maximizing benefit for minimum cost. The constraint to be satisfied is that the annual (fiscal) NMP costs -- as a program — must not exceed the expected budget. Thus, for example, saving on launch vehicle costs directly adds to the pool of funds for advanced technology development, spacecraft. and operations. This policy enhances incentives to bias launch vehicle selections to the smaller end.

Unfortunately, 1995 was a dismal year for the U.S. small launch vehicle community. Three of four attempts failed. The situation for NMP is that many of the candidate launch vehicles for the early missions arc either existing yet unproven designs (due to failure) or ncw designs. This situation adds some unwanted risk to the early NMP mission development schedules, but the long-term view remains promising. In several cases other customers — inchrding NASA — arc committed to usc these vehicles or related configurations before the expected NMP launches.

Synergies between NMP missions

The "P" in NMP suggests an integrated series of missions. The NMP ADT was formed primarily to address this issue. The challenge is to not only define the correct mix of individual missions, but also to put them in some sort of logical order, weighing all of the key constraints and issues outlined in this paper.

Though the baseline missions in the first NMP block arc distinctly different from each other (especially the deep-space missions), some definable factors can be used to logically connect thcm to each other and order thcm in some rational way. Many of these factors have been briefly addressed above, such as:

- Relative priorities of needed capabilities and technologies
- Expected readiness dates of the advanced technology candidates
- Expected NMP funding profile, especially the ramp-up phase
- Latest acceptable first launch date, and other non-technical factors
- Anticipated launch frequency for the deep-space and Earth-orbiting series
- Validation approach for the advanced tczhnologics/capabilities, especially those needing phased validation
- Commonality between missions (architecture, mission type, hardware, software, etc.)
- Launch windows (for meeting small-body targets or co-orbiting with other spacecraft)
- Expected readiness dates of the candidate launch vehicles
- Consequences of mission failure at the program level (the 'ripple effect')
- Desires of key stakeholders (NASA, industrial par'hers, academia: science community, public. etc.)

Benefits to future NASA missions

NMP's focus is on the longer term, say 2005 and beyond. It is targeted to primarily address the expected key challenges -- the 'tall tent poles' -- associated with missions anticipated for this period, and to enable man y of the needed capabilities. Though the general nature of science missions planned for 2005 and beyond is understood (more smaller spacecraft, networks, focused science, etc.), the details have yet to be articulated. It is therefore difficult to shape the NM}' missions directly by responding to detailed mission and system requirements passed down from these future missions, because they simply don't exist,

The alternate approach adopted by the program is to interact regularly with the NMP SWG and the various experts in the advanced technology community to better understand a) the types of missions wc most likely will want to do, b) the reasons why wc can't do thcm now (typically because of technical gaps or because of the estimated expense, or both), and c) what likely advanced technologies might provide the needed capabilities at acceptable cost.

As anyone familiar with the advanced technology world might expect, there arc always ten times more candidate advanced technologies to pursue than available funding will allow. For NMP, this simple fact means that broad applicability to future missions is onc important filter to use when dowselecting the advanced technology list. This is not the only filter, but certainly One. It has not been applied universal 1 y, however. For instance, a high priority for NMP is to demonstrate and enable selected space-based interferometer technologies. Few of these capabilities are directly applicable to other mission types, so the broad applicability filter was not applied to them; the higher objective of getting into the space-based interferometry was judged to be more important at the program level.

The NMP Earth-orbiting missions are specifically connected with an existing NASA Program: the Earth Observing System (EOS). NMP is treated by EOS Program managers as the advanced technology development arm for their program --- but only for EOS missions targeted to launch in about 2002 and beyond, and chiefly in the advanced instrument technology area. Detailed plans for this phase of EOS are currently under review.

It maybe that some of the original plans for continuation of large, multi-instrument platforms well into the early decades of the next century will be scrapped in favor of' small-satellite-based mission architectures. Should this be the case, NMP would likely make a more direct contribution to EOS by virtue of its focus in this area.

What about benefits to nearer-term NASA missions already on the books? NMP's policy is to attempt as much as possible to enhance these missions with infusions of NMP-validated advanced technologies – often via joint collaborations — but to not allow these near-term missions and their needs drive the content of the program. NMP is not viewed as the enabling technology development arm of any near-term mission, though fruitful collaborations are underway between NMP and the Mars Exploration Program, Discovery Program, Pluto Express, and others. NMP is also engaged in active, collaborations with the U.S. Air force/Phillips Laboratory and the Ballistic Missile Defense Organization (BMDO) in several areas, Products from these efforts will likely enhance selected near-term projects in these organizations.

Funding profile and costing issues

Another interesting factor that had to be seriously worked into the first block of missions was the implications of the NMP funding ramp-up. Funding for the first two years of the program (fiscal 1996 and 1997) has been set at 3/5 of that expected for subsequent years. This has been the plan since late 1994 when NMP was in its early planning stages. The ADT concluded early in its mission definition efforts that this profile would likely force the program to scale back on the scope of the second deep-space mission, The result is that this mission is a piggyback-class mission rather than one involving a dedicated launch,

Another key element of the mission definition work is the issue of co-funding from other non-NMP sources within NASA as well as non-NASA sources, such as industry and the U.S. Air Force. A significant fraction of the cost for the first deep-space mission will be borne by these sources, primarily for advanced technology development.

With this discussion in mind, this paper concludes with a brief high-level description of the currently baselined NMP missions, as of early 1996. All will mature in coming months and years, and others will be added to the plan. Consider these descriptions therefore as snapshots or NMP's status in this area. None of these missions have been assigned a formal name, so they are referred to simply as DS 1, DS2, DS3 and EO1, where DS and EO stand for "deep-space" and "Earth-orbiting", respectively. Again, the earliest anticipated launch dates are approximately:

DS 1 1998 January
EO1 1998 December
DS2 1999 January
DS3 2000 July

Baseline Deep-space Missions

DS1

The first planned deep space mission — and the first NMP mission will validate a complement of advanced technologies needed by a broad mix of future NASA science missions: advanced miniaturized avionics, miniaturized deep-space telecommunications equipment, advanced batteries and solar array technology, one or more prototypes of advanced miniaturized science instruments such as imaging spectrometers, and various types of onboard autonomy, such as that which enables autonomous guidance, navigation and control. Also slated for validation on this mission is solar electric propulsion (SEP). One 30-cm-diameter ion thruster will supply the primary source of thrust for the vehicle, generating thrust levels of 10 to 100 milli-Newtons depending on the commanded setting. Xenon gas is the propellant.

To prove out these technologies, four mission types were investigated as candidates: a SEP-propelled spiral from the Earth to the Moon, followed by a lunar gravity assist and a flyby of a near-Ffirth asteroid; a rendezvous with a near-Mwth asteroid; a multiple flyby sequence of a near-F2ulh asteroid and a comet; and a comet rendezvous. For several reasons, the asteroid/comet flyby profile was ultimately selected. Multiple launch opportunities in 1998 allow both types of targets to be visited within 18 months to two years from launch, using a Lockheed-Martin LMLV-3-class launch vehicle.

Extended mission opportunities exist which include one or more additional small-body flybys.

Since very early in the definition phase for this mission (early October 1995), Spectrum Astro, Inc., from Gilbert, Arizona, has been participating as the DS 1 industry partner.

DS2

The second planned deep-space advanced technology validation mission seeks to demonstrate prototypical terrestrial planet micropenetrator technologies. A wide variety of future science missions require this capability. One or two of these 'microprobes', consisting of a very low-mass aeroshell and very low-mass penetrator system, will be carried to Mars by the cruise stage of the Mars '98 lander mission, one of two launches planned (this one in early 1999) during the 1998-99 Mars window by NASA's Mars Exploration Program.

Following a 6- to 10-month cruise, the small systems --- approximately 2 kilograms each — will be separated from the cruise stage about 10 days from Mars entry. They are designed to self-orient into the proper atmospheric entry angle regardless of entry interface attitude. They then ballistically enter and descend without parachutes or any other mechanical or propulsive devices, and ultimately impact the surface of' Mars at approximately 150 meters per second. The small 1-kilogram micropenetrator punches through the aeroshell and finally comes to a stop about 0.5 meter below the surface. A small aftbody with a communications antenna remains on the surface, connected to the subsurface package by a coaxial cable.

The elements of the microprobe system include a suite of highly miniaturized components needed for most future micropenetrator systems: batteries, power electronics, control and data handling microelectronics, telecommunications equipment and antenna, etc. For the NMP demonstration, various options have been identified for the inclusion of a prototype microinstrument into the design to demonstrate that the micropenetrator technology indeed has the capability to acquire and relay a meaningful measurement to an orbiting craft, assumed to be the Mars '96 orbiter.

DS3

The third planned deep-space validation mission is a three-spacwaft, free-flying interferometer placed in solar orbit --- essentially the same orbit the Earth takes around the Sun each year —by a single launch. Owing to employment of kilometer-long (or longer) baselines, separated-spacecraft, freefl ying interferometers hold the potential for enabling dramatic breakthroughs in astrophysics by virtue of their unparalleled capability for resolving distant astronomical objects. The first demonstration of this observing technique in space by NM}' will place NASA on a path toward using larger, more sophisticated versions of such instruments to detect, image and characterize Earth-like. planets around other stars in our galaxy.

Technical challenges to be taken on by NMP with this six-month mission include faint starlight detection (down to 14th magnitude) with two spacecraft; use of actively-controlled optics to manipulate and combine the starlight from the two collector spacecraft in the combiner spacecraft with 10 nanometer control; use of a laser metrology system to precisely measure the starlight path lengths and optical baselines between the three spacecraft; use of a laser-based 'kilometric optical gyro' to measure the overall rotation rates of the three-spacecraft constel lation during operations; precise stationkeeping for all three spacecraft with control to the centimeter level; and techniques for initializing the configuration of the constellation following launch vehicle separation.

Baseline Earth-orbiting Missions

EO1

'1'bough still somewhat tentative pending final NASA HQ approval, the first NMP Earth-orbiting mission is likely to be a demonstration and validation of an advanced land imaging capability, targeted at proving out a new advanced instrument system to replace that employed in the *Landsat* series. Besides providing the same data types and bands as those generated by *Landsat, the* prototypical advanced instrument may be hyperspectral. Advanced onboard data handling and possibly data editing/reduction capabilities might also be demonstrated, as might selected autonomous operations techniques.

EO2, EO3

Several promising candidates for these missions have been identified, but they are still undergoing study and review.

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References (0.2)

1. Casani, E. K., Wilson, B. W. and Ridenoure, R. W.; 1996 January 9: *The New Millennium Program: Positioning NASA for Ambitious Space and Earth Science Missions for the 21s1 Century*; Paper and presentation for the special session on future space and Earth sciences missions at the Space Technology and Applications International Forum (STAIF-96), 1996 January 7-11, Albuquerque, NM.

2. Casani, E. K., and Wilson, B. W.; 1996 January 17: *The New Millennium Program: Technology Development for (he 21s[Century;* AIAA 34th Aerospace Scicnces Meeting and Exhibit, 1996 January Reno, NV, Paper #AIAA 96-0696.

3. Alkalai, L.; 1996 January 17: *A* 3-D *Micro-Avionics Architecture for the New Millennium Program;* AIAA 34th Aerospace Sciences Meeting and Exhibit, 1996 January Reno, NV, Paper #AIAA 96-0697.

4. Hecht, M.; 1996 January 17: *Microinstruments and Microelectromechan ical Systems (MEMS) in Support of Earth and Space Science in the New Millennium;* AIAA *34th* Aerospace Sciences Meeting and Exhibit, 1996 January Reno, NV, Paper #AIAA 96-0698.

5. Man, G., and Aljabri, A.; 1996 January 17: *Rapid Prototyping of Autonomous GN& C';* AIAA 34th Aerospace Sciences Meeting and Exhibit, 1996 January Reno, NV, Paper #AIAA 96-0699.

6. Rafferty, W., Fujikawa, G., Perko, K., and Rascoe, D..; 1996 January 17: Small *Spacecraft Telecommunications for the Next Millennium;* AIAA 34th Aerospace Sciences Meeting and Exhibit, 1996 January Reno, NV, Paper #AIAA *96-0700.*

7. Sercel, J., and Hanks, B.; 1996 January 17: *Modular Multifunctional Systems -- Breakthrough in Lo w-Cost, Lightweight and Large Aperture Systems for the 21st Century;* AIAA 34th Aerospace Sciences Meeting and Exhibit, 1996 January Reno, NV, Paper #AIAA 96-0702.